ACTIVE MEMORY COMMAND ENGINE AND METHOD

TECHNICAL FIELD

[001]   The invention relates memory devices, and, more particularly, to a system and method for internally supplying processing element commands and memory device commands in an active memory device.

BACKGROUND OF THE INVENTION

[002]   A common computer processing task involves sequentially processing large numbers of data items, such as data corresponding to each of a large number of pixels in an array. Processing data in this manner normally requires fetching each item of data from a memory device, performing a mathematical or logical calculation on that data, and then returning the processed data to the memory device. Performing such processing tasks at high speed is greatly facilitated by a high data bandwidth between the processor and the memory devices. The data bandwidth between a processor and a memory device is proportional to the width of a data path between the processor and the memory device and the frequency at which the data are clocked between the processor and the memory device. Therefore, increasing either of these parameters will increase the data bandwidth between the processor and memory device, and hence the rate at which data can be processed.

[003]   A memory device having its own processing resource is known as an active memory. Conventional active memory devices have been provided for mainframe computers in the form of discrete memory devices provided with dedicated processing resources. However, it is now possible to fabricate a memory device, particularly a dynamic random access memory ("DRAM") device, and one or more processors on a single integrated circuit chip. Single chip active memories have several advantageous properties. First, the data path between the DRAM device and the processor can be

made very wide to provide a high data bandwidth between the DRAM device and the processor. In contrast, the data path between a discrete DRAM device and a processor is normally limited by constraints on the size of external data buses. Further, because the DRAM device and the processor are on the same chip, the speed at which data can be clocked between the DRAM device and the processor can be relatively high, which also maximizes data bandwidth. The cost of an active memory fabricated on a single chip can is also less than the cost of a discrete memory device coupled to an external processor.

[004] Although a wide data path can provide significant benefits, actually realizing these benefits requires that the processing bandwidth of the processor be high enough to keep up with the high bandwidth of the wide data path. One technique for rapidly processing data provided through a wide data path is to perform parallel processing of the data. For example, the data can be processed by a large number of processing elements ("PEs") each of which processes a respective group of the data bits. One type of parallel processor is known as a single instruction, multiple data ("SIMD") processor. In a SIMD processor, each of a large number of PEs simultaneously receive the same instructions, but they each process separate data. The instructions are generally provided to the PE's by a suitable device, such as a microprocessor. The advantages of SIMD processing are that SIMD processing has simple control, efficiently uses available data bandwidth, and requires minimal logic hardware overhead.

[005] An active memory device can be implemented by fabricating a large number of SIMD PEs and a DRAM on a single chip, and coupling each of the PEs to respective groups of columns of the DRAM. The instructions are provided to the PEs from an external device, such as a microprocessor. The number of PE's included on the chip can be very large, thereby resulting in a massively parallel processor capable of processing vast amounts of data. However, this capability can be achieved only by providing instructions to the PEs at a rate that is fast enough to allow them to operate at their maximum speed. It can require more time to couple instructions to the PEs from an external device, such as a microprocessor, than the time required to execute the

instructions. Under these circumstances, the PEs will be operating at less than their maximum processing speed.

[006]   There is therefore a need for a system and method for more rapidly providing instructions to SIMD PE's that are embedded in a DRAM.

SUMMARY OF THE INVENTION

[007]   An integrated circuit active memory device is preferably fabricated on a single semiconductor substrate. The active memory device includes a memory device coupled to an array of processing elements through a data bus having a plurality of data bus bits. Each processing elements are preferably coupled to a respective group of the data bus bits, and each of the processing elements have an instruction input coupled to receive processing element instructions for controlling the operation of the processing elements. The processing element instructions are provided by an array control unit, and memory device instructions for controlling the operation of the memory device are provided by a memory device control unit. The array control unit is coupled to the processing elements in the array, and it is operable to generate and to couple the processing element instructions to the processing elements. Each of a plurality of sets of processing element instructions are generated responsive to a respective one of a plurality; of array control unit commands applied to a command input of the array control unit. A memory control unit coupled to the memory device is operable to generate and to couple respective sets of memory commands to the memory device responsive to each of a plurality of memory control unit commands applied to a command input of the memory control unit. Respective sets of the array control unit commands and respective sets of the memory control unit commands are provided by a command engine responsive to respective task commands applied to a task command input of the command engine.

BRIEF DESCRIPTION OF THE DRAWINGS

[008]   Figure 1 is a block diagram of an active memory device according to one embodiment of the invention.

[009]   Figure 2 is a block diagram of a command engine used in the active memory device of Figure 1.

[010]   Figure 3 is a block and logic diagram of the command engine of Figure 2 according to one embodiment of the invention.

[011]   Figure 4 is a block diagram of a computer system using the command engine of Figure 1 according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[012]   Figure 1 shows an active memory device 10 according to one embodiment of the invention. The memory device 10 is coupled to a host 14, such as a microprocessor, although it may be coupled to other devices that supply high –level instructions to the memory device 10. The memory device 10 includes a first in, first out ("FIFO") buffer 18 that receives high level tasks from the host 14. Each task includes a task command and may include a task address. The received task commands are buffered by the FIFO buffer 18 and passed to a command engine unit 20 at the proper time and in the order in which they are received. The command engine unit 20 generates respective sequences of commands corresponding to received task commands. As described in greater detail below, the commands are at a lower level than the task commands received by the command engine unit 20. The commands are coupled from the command engine unit 20 to either a processing element ("PE") FIFO buffer 24 or a dynamic random access memory ("DRAM") FIFO buffer 28 depending upon whether the commands are PE commands or DRAM commands. If the commands are PE commands, they passed to the PE FIFO buffer 24 and then from the FIFO buffer 24 to a processing array control unit ("ACU") 30. If the commands are DRAM commands, they are passed to the DRAM FIFO buffer 28 and then to a DRAM Control Unit ("DCU") 34.

[013]   As explained in greater detail below, the ACU 30 executes an intrinsic routine containing several instructions responsive to the command from the FIFO buffer 24, and these instructions are executed by an array of PEs 40. The PE's operate as SIMD processors in which all of the PEs 40 receive and simultaneously execute the same instructions, but they do so on different data or operands. In the embodiment shown in

Figure 1, there are 256 PE's 40 each of which is coupled to receive 8 bits of data from the DRAM 44 through register files 46. In the embodiment shown in Figure 1, the DRAM 44 stores 16M bytes of data. However, it should be understood that the number of PEs used in the active memory device 10 can be greater or lesser than 256, and the storage capacity of the DRAM 44 can be greater or lesser than 16 Mbytes.

[014]   Different intrinsic routines containing different instructions are issued by the ACU 30 for different commands received from the FIFO buffer 24. As also explained below, the DCU 34 issues memory commands and addresses responsive to commands from the DRAM FIFO buffer 34. In response, data are either read from a DRAM 44 and transferred to the register files 46, or written to the DRAM 44 from the register files 46. The register files 46 are also available to the PE's 40. The ACU 30 and the DCU 34 are coupled to each other so the operation of each of them can be synchronized to the other. The ACU 30 and DCU 34 are also coupled directly to the register files 38 so that they can control their operation and timing.

[015]   With further reference to Figure 1, the DRAM 44 may also be accessed by the host 14 directly through a host/memory interface ("HMI") port 48. The HMI port is adapted to receives a command set that is substantially similar to the command set of a conventional SDRAM except that it includes signals for performing a "handshaking" function with the host 14. These commands include, for example, ACTIVE, PRECHARGE, READ, WRITE, etc. In the embodiment shown in Figure 1, the HMI port 48 includes a 32-bit data bus and a 14-bit address bus, which is capable of addressing 16,384 pages of 256 words. The address mapping mode is configurable to allow data to be accessed as 8, 16 or 32 bit words.

[016]   In a typical processing task, data read from the DRAM 44 are stored in the register files 46. The data stored in the register files 46 are then transferred to the PEs 40 where they become one or more operands for processing by the PEs 40. Groups of data bits read from or written to each set of DRAM columns are processed by respective PEs 40. The data resulting from the processing are then transferred from the PEs 40

and stored in the register files 46. Finally, the results data stored in the register files 46 are written to the DRAM 44.

[017]   The PEs 40 operate in synchronism with a processor clock signal (not shown in Figure 1). The number of processor clock cycles required to perform a task will depend upon the nature of the task and the number of operands that must be fetched and then stored to complete the task. In the embodiment of Figure 1, DRAM operations, such as writing data to and reading data from the DRAM 44, requires about 16 processor clock cycles. Therefore, for example, if a task requires transferring three operands into and of the DRAM 44, the task will require a minimum of 48 cycles.

[018]   One embodiment of the command engine unit 20 is shown in Figure 2. The command engine unit 20 includes a command engine 50 that issues either ACU commands or DCU commands responsive to task commands received from the FIFO buffer 18. The command engine 50 passes ACU commands to the PE FIFO buffer 24 through a multiplexer 52, and DCU commands to the DRAM FIFO buffer 28 through a multiplexer 54. The operations of the FIFO buffers are controlled by a FIFO buffer control unit 56. The multiplexers 52, 54 also receive inputs directly from the FIFO buffer 18. The multiplexers 52, 54 couple the outputs from the command engine 50 to the ACU 30 and DCU 34, respectively, in normal operation. However, the multiplexer 52 may couple the host 14 directly to the ACU 30, and the multiplexer 54 may couple the host 14 directly to the DCU 34 for diagnostic purposes and, under some circumstances, for programming and controlling the ACU 30 and DCU 34.

[019]   In the embodiment shown in Figure 2, the task commands passed to the command logic each have 23 bits, and they have the format shown in the following Table 1:

Table 1

22	21	20	19	18	17	16	Bits 15-0
Device Select		SG	WT	Device Specific Function			Command Data

[020]   Bits 22 and 21 identify the task as either a PE task or a DRAM task, the SG bit is a signal flag, the WT bit is a wait flag that is used with the signal flag SG to perform handshaking functions during the transfer of data, bits 18-16 designate the function

performed by the task (*e.g.*, jump, page or data for a PE task or read, write, refresh, etc. for a DRAM task), and bits 15-0 comprise a 16-bit data word that can constitute an operation code or data that is either operated on or used to generate an address. In operation, for example, the first task passed to the command logic may designate a specific operation to be performed by the PEs 40 on an operand received from the DRAM 44. The task will include device select bits to select either the ACU 30 or the DCU 34, bits 18-16 that indicate a specific function, and bits 15-0 that may constitute an operation code corresponding to the specific operation. The wait flag WT may also be set to indicate to the PEs 40 that they should not immediately perform the function. The next task may be to transfer the operand from the DRAM 44. In such case, the task command will include device bits to select the DCU 34, bits 18-16 that identify a function, and bits 15-0 can provide the address in the DRAM 44 from which the operand is being transferred. The task will also include a signal flag SG that will be coupled from the DCU 34 to the ACU 30 to specify that the PEs 40 can now perform the specified processing function. After the operand has been processed by the PEs 40, the results data are passed from the PEs 40 back to the DRAM 44 using a similar handshaking sequence.

[021]   The instruction set for the command engine 20 is shown in the following Table 2:

Table 2

Gr.	Mnemonic	Operation	Op code	Comment
0	Control Instructions			
	NOP	PC=PC+1	0000 0000 0000 0000	
	ALERT		0000 0001 0000 0000	Send alert (interrupt) to host.
	WAITSYS		0000 1111 0000 0000	Wait for data in FIFO and branch.
	Shifts			
	RL	C=U(15),U=(U<<1,C)	0000 0110 0000 0000	Rotate left through carry

Gr.	Mnemonic	Operation	Op code	Comment
	RR	C=U(0),U=(C,U>>1)	0000 0111 0000 0000	Rotate right through carry
0	**Bit Operations**			
	BITS	U=U|(0x8000>>b)	0000 1000 0000 bbbb	Bit set
	BITC	U=U&~(0x8000>>b)	0000 1001 0000 bbbb	Bit clear
	BITT	Z=((U&(0x8000>>b)) ==0	0000 1010 0000 bbbb	Bit test => Z
1	**Relative Branch**			
	BRR cond?@BRR+#i	PC=cond?@BRR+3+ #i	0001 cccc iiii iiii	Relative branch
2	**Precalculated Branch/Call**			
	BR cond?reg	PC=cond?reg	0010 cccc 00rr rrrr	Precalculated target in register.
	CALL cond?reg	PC=cond?reg	0010 cccc 10rr rrrr	Precalculated target in register.
3	**Arithmetic and Logical**			
	ADD reg	U=U+R	0011 m100 00rr rrrr	
	ADDC reg	U=U+R+C	0011 m100 10rr rrrr	
	SUB reg	U=U-R	0011 m101 00rr rrrr	
	SUBC reg	U=U-R+C	0011 M101 10rr rrrr	
	AND reg	U=U&R	0011 m110 00rr rrrr	
	OR reg	U=U|R	0011 m110 10rr rrrr	
	XOR reg	U=U^R	0011 m111 00rr rrrr	
	<spare> reg	U=U?R	0011 m111 10rr rrrr	

Gr.	Mnemonic	Operation	Op code	Comment
4	**Immediate Add**			
	ADD #imm	U=U+#i	0100 m100 iiii iiii	#i is sign extended to 16 bits
5,6	**Immediates**			
5	IMME n	U=decoded(N)	0101 m100 nnnn nnnn	See Table 2-3 for encoding of N
6	IMM k	U=(#k,#k)	0110 m100 kkkk kkkk	K is copied to both bytes

Gr.	Mnemonic	Operation	Op c de	Comment
7,8, 9	**Moves**			
7	MOVR reg u	U=R etc	0111 m10X h1rr rrrr	U is modified if U is 1. LS byte is modified if 1 is 1, MS byte is modified if m is 1. Bytes are exchanged if X is 1. Replaces all MOVR, SWAP and MERGE, MOVRL, MOVRH instructions.
8	MOVU reg	R=U	1000 0000 00rr rrrr	
	MOVPG reg	R=PAGE	1000 0010 00rr rrrr	Loads reg with page portion of PC
	MOVPC reg	R=PC	1000 0011 00rr rrrr	Loads reg with @MOVPC+6
	STATUS	R=[status]	1000 10ss ssrr rrrr	Load register from DCU and ACU status. S selects which status register.
	ACU_RESULT	R=[ACU result]	1000 11wd 00rr rrrr	Load register from ACU Out FIFO. If w is set, instruction will wait until FIFO empty flag is off before reading the FIFO and continuing execution. If d is set read will be destructive: the next word will be fetched from the FIFO.

Gr.	Mnemonic	Operation	Op code	Comment
9	MOVS reg {u,r2a}	R U=inF	1001 m1w0 00rr rrrr	Load register directly from in FIFO. U is modified if U is 1. RF reg is modified if w=1.
	MOVR_PG	NEXT_PAGE=reg	1001 0000 0100 0000	(Mnemonic is MOVU)
	MOVU_S	outF=U	1001 0000 1000 0000	(Mnemonic is MOVU)
	MOVR_S reg	outF=R	1001 0000 11rr rrrr	(Mnemonic is MOVR)
A	**Skip and SETSn**			
	.SKIP	if (cond) skip next instructions	1010 cccc 0000 dddd	C is condition. D is number of instructions to skip-1
	SETS	Sn = <cond>	1010 cccc ss00 0000	C is condition. S determines which S flag is loaded (S1 or S2).
B-C	**Commands**			
B	DCU_FIFO	DCU_FIFO = DCU_OP(s,w,d)U	1011 ddss wwtt t0000	T: DCU task type: see Table 2-2. D: defer buffer. If 0 task is written immediately. If 1,2,3 command is pushed into the defer buffer of that number. S: Select generation of signal bit (s) in DCU command: S=0 ->s=0; S=1 ->s=S1 flag; S=2 ->s=S2 flag; S=3 ->s=1. W: Select

Gr.	Mnemonic	Operation	Op code	Comment
				generation of wait bit (w) in DCU command: W=0 ->w=0; W=1 ->w=S1; W=2 ->w=S2; W=3 ->w=1.
C	ACU_DATA	ACU_InFIFO=R ACU_InFIFO=Page[R]	1100 ff01 00rr rrrr	Data read from register file. F: ACU function: 0 – data; 1 – (reserved); 2 – page; (3 – intrinsic call).
	ACU_TASK	ACU_InFIFO=OPCALL	1100 11ss wwrr rrrr	Intrinsic routine address held in register. S and W do the same sa for DCU_FIFO.
D	Unused, Reserved			
E	Return Stack PUSH and POP			
	PUSH	*(++rsp)<=U	1110 0000 0000 0000	rsp = return stack pointer. Note pre-increment
	POP	U<=*(rso--)	1110 1000 0000 0000	Note post-decrement.
F	Memory Operations: multicycle instructions			
	M_LOAD	U<=*R	1111 0000 00rr rrrr	Load U from memory, addressed by register
	M_LOADP	U<=*R++	1111 0010 00rr rrrr	Load U from memory, post-increment address register
	M_LOADN	U<=*R—	1111 0100 00rr rrrr	Load U from memory, post-decrement address register

Gr.	Mnemonic	Operation	Op code	Comment
	M_STORE	*R<=U	1111 1000 00rr rrrr	Store U in memory, addressed by register
Gr.	**Mnemonic**	**Operation**	**Op code**	**Comment**
	M_STOREP	*R++<=U	1111 1010 00rr rrrr	Store U in memory, post-decrement address register.
	M_STORE N	*R==<=U	1111 1100 00rr rrrr	Store U in memory, post-decrement address register.

[022]   One embodiment of the command engine 50 that may be used in the command engine unit 20 is shown in Figure 3. The task commands are coupled to the command engine 50 from the FIFO buffer 18 (Figure 2) and are applied to an input FIFO buffer 58. The flag bits 20, 19 and the Device Specific Function bits 18-16 are passed to a Cycle, Decode and Microwait Control Unit 60, which determines the function being performed by the task and coordinates handshaking using the SG and WT flags. The remaining Device Select bits 22, 21 and the Command Data bits 15-0 are routed to several locations. The output of the FIFO buffer 58 is coupled to a control input of a multiplexer 62. If the Command Data corresponds to an instruction that the command engine 50 pass data back to the host 14, the multiplexer 62 is enabled to pass the output data to an output FIFO buffer 64. The Cycle, Decode and Microwait Control Unit 60 is also operable to stall the operation of the FIFO buffers 58, 62 when they are full.

[023]   If the device specific function bits correspond to a jump in which instructions are to be executed starting from a jump address, the jump address is coupled through a first multiplexer 66 and a second multiplexer 68 to set a program counter 70 and a delayed program counter 72 to the jump address. The jump address is then used to address an Instruction Cache Memory and Controller 76, which outputs an instruction 78 stored at the jump address. The Instruction Cache Memory and Controller 76 is normally loaded by a cache controller (not shown) with instructions from a program

memory (not shown), both of which are included in a computer system (not shown) coupled to the active memory 10. The Instruction Cache Memory and Controller 76 can be loaded with different sets of instructions depending upon the type of task commands that will be passed to the active memory 10.

[024]   A portion of the instruction 78 is decoded by a microinstruction decoder 80, which outputs a corresponding microinstruction to a microinstruction register 82. The microinstructions control the internal operation of the command engine 50, such as the FIFO buffers, multiplexers, etc. The microinstructions are also used to form all or portions of DCU and ACU commands. The signal paths from the microinstruction register 82 are numerous, and, in the interest of clarity, have been omitted from Figure 3. The DCU commands and ACU commands are shown in Groups B and C, respectively, of Table 2. The DCU commands shown in Group B include defer bits "dd" to delay the operation of a command, signal and wait bits "ss" and "ww" bits that are used as described above, and a task type "t," which is normally included in the task received from the host 14. The value of the signal and wait bits are stored in respective registers 132, 133. As explained above, the defer values "dd" can be part of a DCU command, as shown in Table 3.

[025]   The DCU commands are shown in Table 3 as follows:

Table 3

Bit 20	Bit 19	Bits 18-16	Bits 15-8	Bits 7-0
Flags		Function	Data	
SG		0:Null		
		1:RFA_L	Byte count	Array RF address
		2:Read	DRAM Base address	
		3:Write	DRAM Base address	
		4:Power-up		
		5:Refresh		
		6:Sleep		
		7:Ld Mode		

As shown in Table 3, the DCU commands are Null, Power up, Refresh, Sleep and Load Mode, as well as Read and Write, which are accompanied by a Base address in the DRAM 44, and a register file address ("RFA_1") command, which is accompanied by the Byte count indicative of the number of bytes that are to be transferred to or from the register files 46, and an Array RF address, which is the address of the register file to or from which the data will be transferred.

[026]   The ACU commands shown in Group C include data commands and task commands, as shown in Table 4:

Table 4

	b20	b19	Bits18-16 Function	Bits 15-0 Data	
Jump	SG	WT	3	Start Address of Microroutine	
Page	0	0	2	(unused)	Page address
Data	0	0	0	Data	

[027]   The data command simply includes 16 bits of data, which are transferred from the register file 120. Data may also be transferred from the ACU 30 to the register file 120 by passing the data designated "acu_ofd" through the multiplexer 124. The task commands include either a jump address or a page address where task instructions are stored.

[028]   As mentioned above, the tasks shown in Table 1 that are passed to the command generator 50 include 16 command data bits, which may constitute data that is to be either operated on or used to form an address. In the event a data word larger than 16 bits is required in an operation corresponding to an instruction, the instruction may be preceded by an immediate instruction, which are shown in Groups 4-6 of Table 2. For example, an Immediate Add instruction shown in Group 4 of Table 2 indicates that a data value having more than 16 bits is to be added to the contents of a U register 96. The immediate instruction is decoded by an immediate instruction decoder 84 and the command data in the instruction is stored in an IMM register 86. The data stored in the IMM register 86 is combined with the command data in the subsequent instruction decoded by the instruction decoder 80 and stored in the microinstruction register 82.

The combined data fields are then passed through a multiplexer 88 to an arithmetic and logic unit ("ALU") 90. The ALU 90 performs an arithmetic or logical operation on the data, and outputs the results to the U register 96. These operations, and the operation codes that correspond to them, are shown in group 3 of Table 2.

[029]   The ALU 90 also provides several conditional values, one of which is selected by a multiplexer 94 for conditional branching of the program. These conditions are shown in Table 5 as follows:

Table 5

Code	Flag	Comment	Code	Flag	Comment
0	Always	Always true	8	Never	Always false
1	C	ALU Carry out	9	NC	!ALU carry out
2	N	ALU result < 0	A	NN	ALU result > 0
3	Z	ALU result = 0	B	NZ	ALU result !=0
4	IFE	Input FIFO empty	C	NIFE	Inut FIFO not empty
5	S1	Signal/wait flag 1	D	NS1	S1 not set
6	S2	Signal/wait flag 2	E	NS2	S2 not set
7	RFE	Result FIFO empty	F	NRFE	Result FIFO not empty

The C, N, Z, NC, NN and NZ flags are provided by the ALU 30. The remaining flags are generated by various conditions that arise in the active memory device 10, such as the condition of FIFO buffers and by being directly set or cleared.

[030]   A signal indicative of a branch conditioned on the variable selected by the multiplexer 94 is coupled to a gate 98, which is enabled by an active BRANCH microinstruction, to cause the multiplexer 68 to couple the jump address from the FIFO buffer 54 to the program counters 70, 72, as previously explained. The ALU 90 may also output a return stack of instructions to be stored in a U register 96 for subsequently restoring the program to a location prior to a branch.

[031]   Assuming there is no branch to a jump address, the count from the program counter 70 is incremented by an adder 100 to provide an incremented instruction count that is stored in a return stack register 104 and is coupled through the multiplexers 66,

68 to write the incremented count to the program counter 70. Each command in a routine corresponding to the task command from the host 14 is thus sequentially executed. The program count is also coupled to an adder 100 that can also receive an offset address forming part of the instruction 78. The adder offsets the program address by a predetermined magnitude to generate a target address that is stored in a target address register 103. This target address is coupled through the multiplexers 66, 68 to write the target address to the program counter 70. The program counter 70 then addresses the Icache memory and controller 76 at a location corresponding to the target address.

[032] If the device specific function bits correspond to a page instruction, a page address is coupled through the multiplexers 66, 64 and stored in a page register 106 associated with the program counter 70. Alternatively, if an operation is a deferred operation, the page address is stored in a page register 108 associated with the delay program counter 72. The address space of the ACU can be increased by combining page addresses from two page instructions. In such case, a first page address is coupled though a multiplexer 110 and stored in a next page register 112. The next page address stored in the register 112 can then be combined with a page address from a subsequent page command to address a larger number of ACU program memory addresses storing ACU instructions.

[033] The DCU commands, which include task bits from the instruction 78 as well as data from the U register, are passed through a DCU FIFO buffer 116. The DCU commands can also be stored in multiple defer buffers 118 and subsequently passed through the FIFO buffer 116. A dcu_cmd may be deferred, for example, if an operation must be carried out in the ACU 30 or PEs 40 before an operation in the DCU 34 or in the DRAM 44 should be carried out. As explained above, the defer values "dd" can be part of a DCU command as shown in Table 3.

[034] The command engine 50 also includes a register file 120 that is addressed by a portion of the instructions 78. The register file 120 receives write data through a multiplexer 124 from various sources, most of which have been previously described.

In particular the register file serves as scratch memory for the command generator 50. In addition to the data previously described, the register file 120 can also store a future program instruction address by incrementing the current program address from the program counter 70 using an adder 126, thereby storing a program address that is two instructions beyond the current instruction. Data read from the register file 120 is temporarily stored in an R12 register 128, where it is available at various locations. For example, the data from the register 128 may be passed though a multiplexer 130 to an output FIFO buffer 134, which then outputs the data to the host 14 (Figure 1). The data from the register 128 is also used by the ALU 90 to perform various operations in connection with data from the U register 96, as shown in Group 3 of Table 2. The register file 120 provides only limited data storage capacity. An SRAM 136 is used to store larger quantities of data, which is transferred to the SRAM 136 from the U register 96. The SRAM 136 is addressed by addresses stored in a memory address register 138.

[035]   Although not shown in detail herein, the ACU 30 and the DCU 34 are slave processors that may be similar in structure and function to the command engine 50. The PEs 40 may be somewhat conventional execution units that operate using basic instructions provided by the ACU 30. The DRAM 44 is essentially the same as a conventional DRAM.

[036]   A computer system 200 using the active memory device 10 of Figure 1 is shown in Figure 4. The computer system 200 includes a processor 202 for performing various computing functions, such as executing specific software to perform specific calculations or tasks. The processor 202 includes a processor bus 204 that normally includes an address bus, a control bus, and a data bus. In addition, the computer system 200 includes one or more input devices 214, such as a keyboard or a mouse, coupled to the processor 202 through a system controller 210 to allow an operator to interface with the computer system 200. Typically, the computer system 200 also includes one or more output devices 216 coupled to the processor 202 through the system controller 210, such output devices typically being a printer or a video terminal. One or more data storage devices 218 are also typically coupled to the processor 202 through the system

controller 210 to store data or retrieve data from external storage media (not shown). Examples of typical storage devices 218 include hard and floppy disks, tape cassettes, and compact disk read-only memories (CD-ROMs). The processor 202 is also typically coupled to a cache memory 226, which is usually static random access memory ("SRAM"). The processor 202 is also coupled through the data bus of the processor bus 204 to the active memory device 10 so that the processor 202 can act as a host 14, as explained above with reference to Figures 1 and 2.

[037]   From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.